Electrothermal Simulation
FLOORS

Michelle Griglione and Mark Law

Scientific Approach

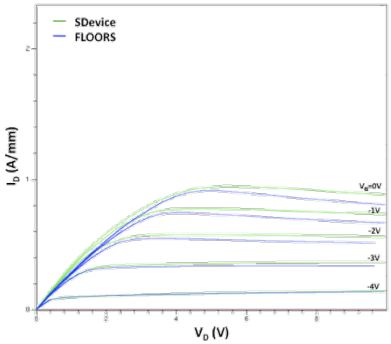
FLOORS

$$H = -\nabla \cdot (P_n T + \phi_n) J_n - (E_C + \frac{3}{2} kT) \nabla \cdot J_n$$

Heat Generation Model Refinement

S/D Resistance Development

Carrier Ionization Development



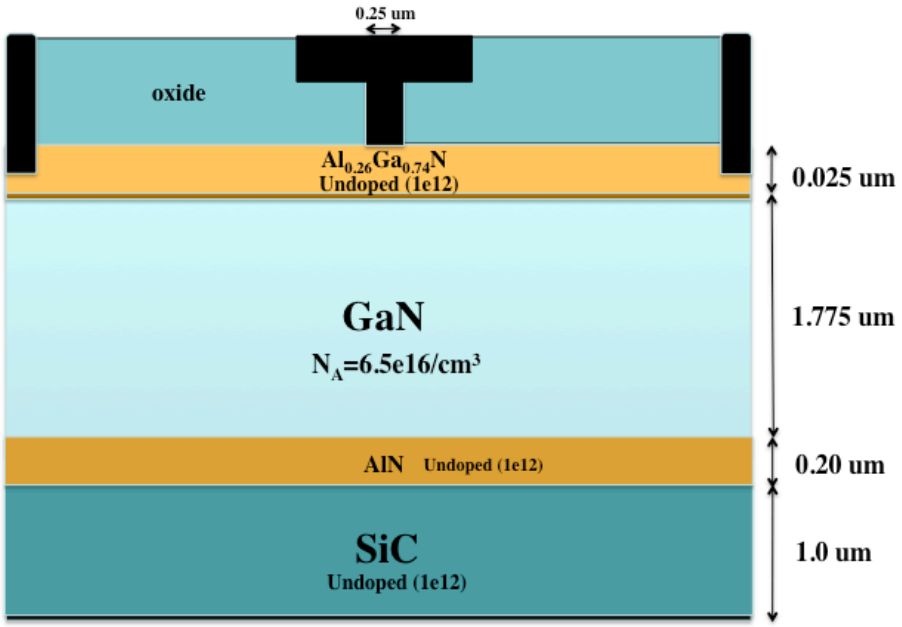
Model & Simulation Calibration

Electrothermal Simulation

- Overview
  - Simulation comparisons with E. Heller/SDevice
  - Carrier ionization implementation
  - Source/drain resistance implementation
  - Current and future work

Current HEMT Structure

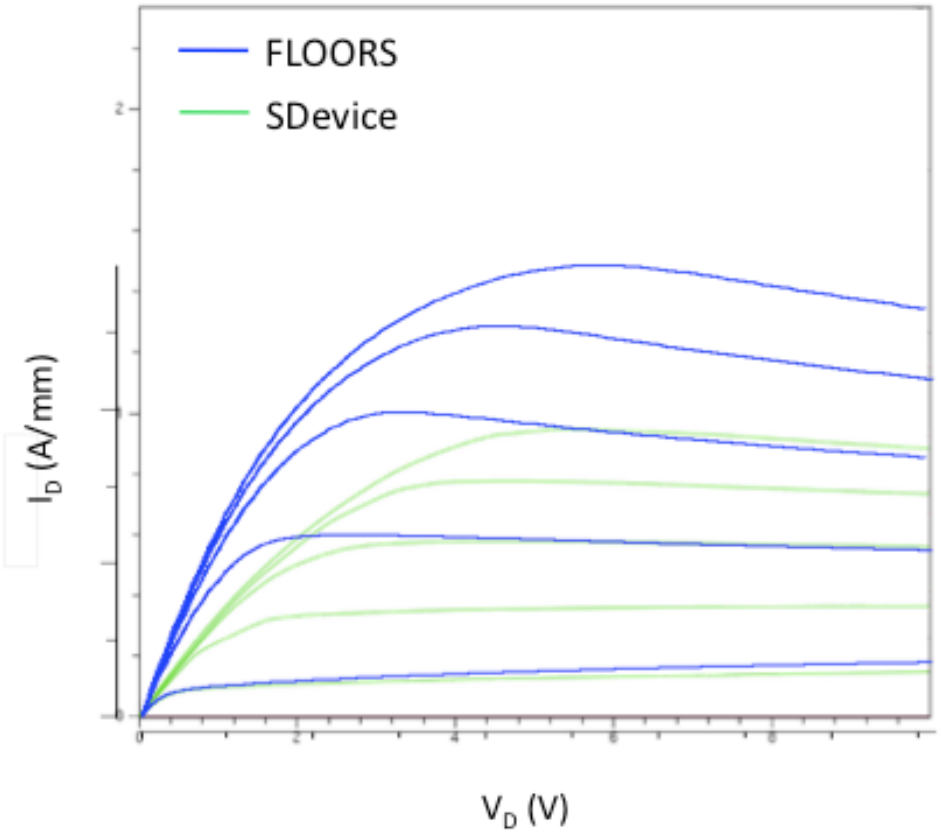
[Not to scale]



No changes since previous review

I_D vs. V_D Curves from Previous Review

- V_G=0 to -4V, V_D=0 to 10V
  - Heller: SDevice (green)
  - FLOORS (blue)
- Comparison to Heller/SDevice simulations
  - FLOORS overshoots by 50%
  - Driven by
    - Mobility differences
    - Source/drain resistance differences
    - Ionized carriers at low V_D? Might affect slope of curve pre-V_{sat}



Carrier Ionization Model Implementation

- Concentration of ionized donors in GaN accounted for through

$$N_A^- = \frac{N_A}{1+g\exp\left(\frac{E_V+E_A-\phi_p}{kT}\right)}$$

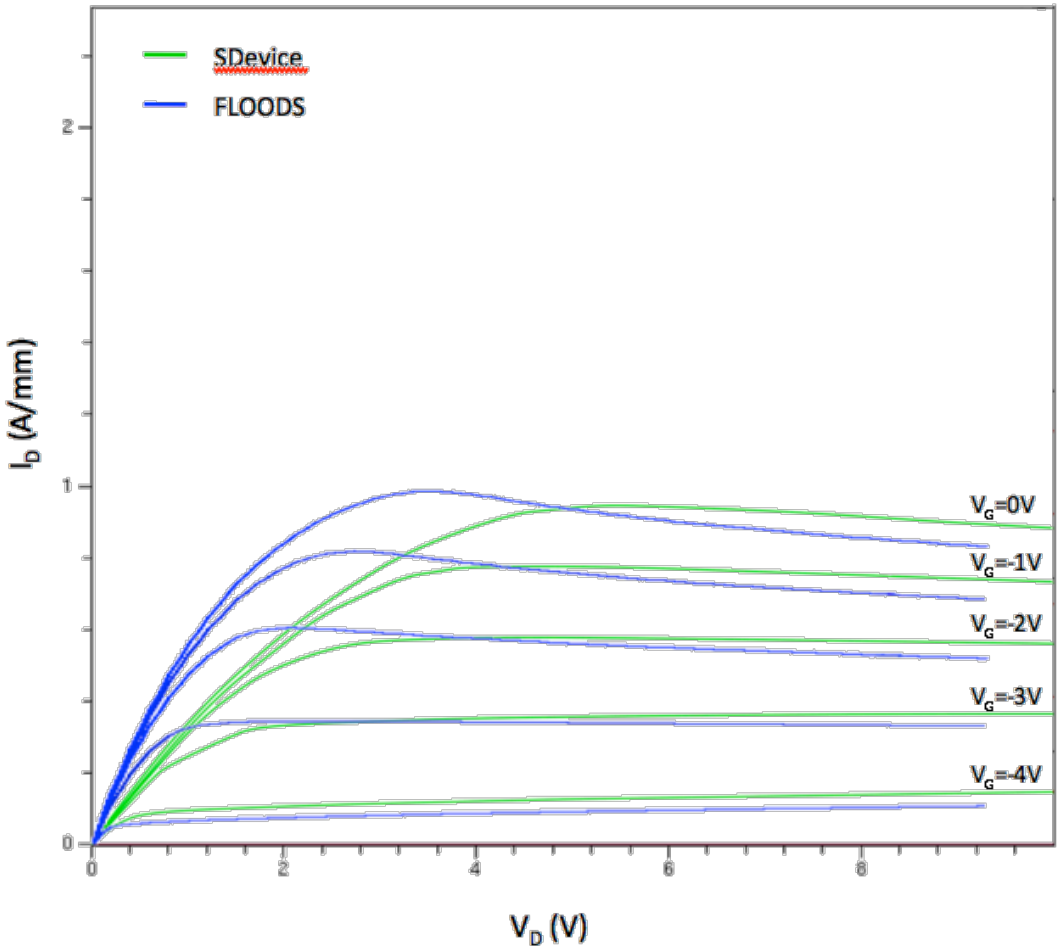
where

- $g \equiv$ ground-state degeneracy of impurity (4 used for GaN acceptors)
- $E_A \equiv$ energy level of acceptor impurity (0.9eV used in FLOORS)
- $\phi_p \equiv$ quasi-fermi level of holes
- $N_A = 6.5\text{x}10^{16}$ (doping level of GaN)

(Sze, Phys. Semi. Dev., p. 24, J. Wiley & Sons, 1981)

IV Comparison with New Models

- Addition of ionization model
  - ~20% drop in I_D
- Correction of mobility model equation error
  - Additional 20% drop in I_D
- I_D values improved but V_{Dsat} lower
  - Source/drain resistance still an issue

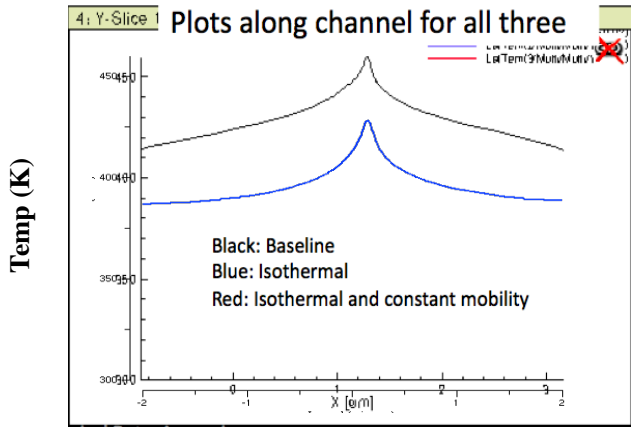


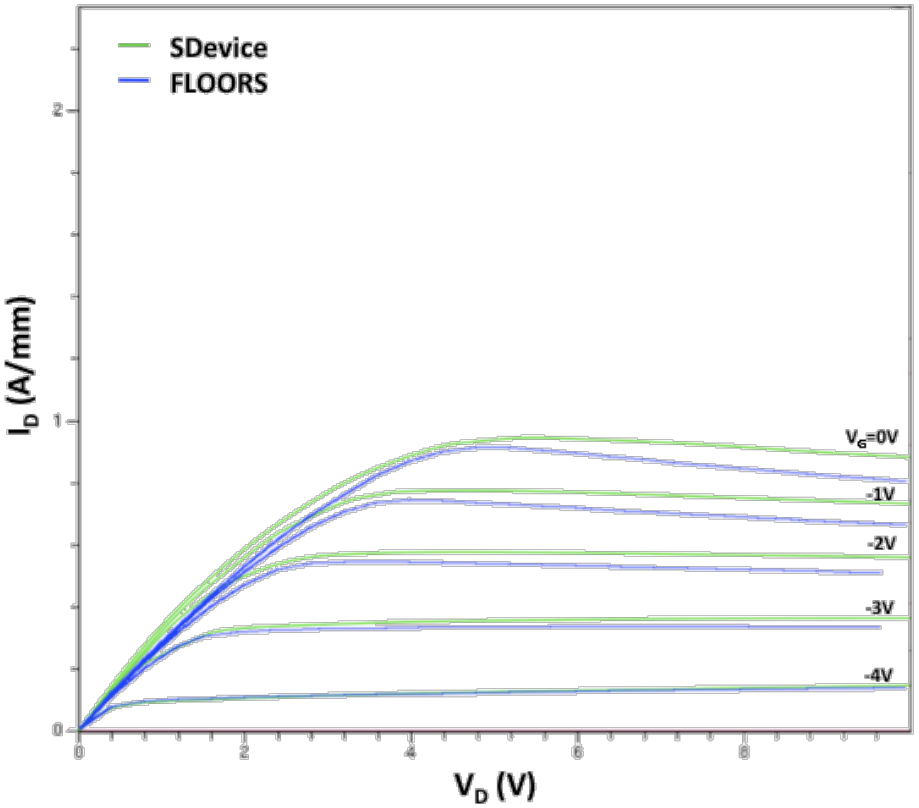
Source /Drain Resistance Implementation

- FLOORS did not have contact resistance feature
- Originally used voltage calibration to account for resistance
  - Calculated as
    - $V_S = 0V+(0.5\Omega*0.881A)=0.4405V$
    - $V_G = 0V$
    - $V_D = 10V-(0.5\Omega*0.881A)=9.5595V$
  - Translates to
    - $V_S = 0V$
    - $V_G = -0.4405V$
    - $V_D = 9.1190V$
- Resistance of device contacts now included in simulation capabilities (Law)
  - Lump resistance per method implemented by Heller in SDevice
  - pdbSetDouble S Qfn Resistance -500 (units accounting for 0.5Ω)
  - pdbSetDouble D Qfn Resistance -500

IV Comparison with New Resistance

- With new resistance feature
  - Best fit yet
  - V_{Dsat} matches well
  - I_{Dsat} matches OK
    - Best at lower V_G
    - Not as good at high V_G and high V_D
      - Overheating? Surprisingly, no
    - Still a question regarding heat generation





Heat Generation in Thermal Transport

- Thermal transport equation for GaN

$$c \cdot (\partial T/\partial t) = \text{div}\,(\kappa \vec{\nabla} T) + H$$

$\varkappa \equiv$ thermal conductivity
$c \equiv$ lattice heat capacity

(Wachutka, IEEE Trans. Comp. Aided Des., **9**, no. 11, 1990)

- Model uses simplest heat generation term, H

$$H = q \cdot \text{div}\,(\phi_n \vec{j}_n - \phi_p \vec{j}_p).$$

where ϕ_n and ϕ_p are quasi-fermi levels of elecs and holes and

$$\vec{j}_n = \mu_n \cdot n \cdot \vec{\nabla} \phi_n$$

$$\vec{j}_p = -\mu_p \cdot p \cdot \vec{\nabla} \phi_p$$

- Looked at using more complicated heat generation term which agrees with SDevice

$$H = -\nabla \cdot [(P_n T + \Phi_n)\vec{J}_n + (P_p T + \Phi_p)\vec{J}_p] - \left(E_C + \frac{3}{2}kT\right)\nabla \cdot \vec{J}_n$$
$$-\left(E_V - \frac{3}{2}kT\right)\nabla \cdot \vec{J}_p + qR_{net}(E_C - E_V + 3kT)$$

From SDevice User Manual ver. A-2007.12

Heat Generation in Thermal Transport

- Simplified equation accounts for negligible hole concentration and R_{net} in device

$$H = -\nabla \cdot (P_n T + \phi_n) J_n - (E_C + \frac{3}{2} kT) \nabla \cdot J_n$$

with

$$\vec{J}_n = -nq\mu_n(\nabla \Phi_n + P_n \nabla T)$$

$$P_n = -\kappa_n \frac{k}{q}\left[\left(\frac{5}{2} - s_n\right) + \ln\left(\frac{N_C}{n}\right)\right] \qquad \text{(thermoelectric power)}$$

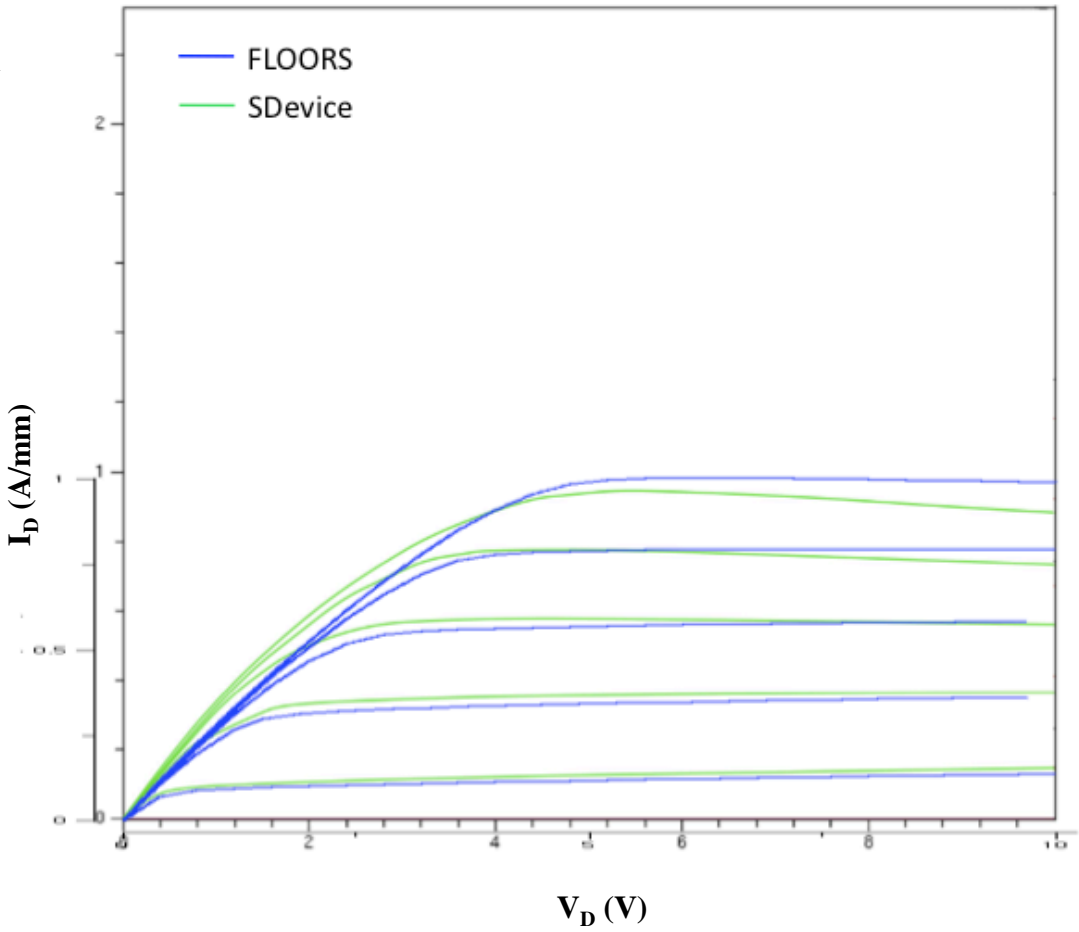
$\kappa_n = 1$

$s_n = 1$

From SDevice User Manual ver. A-2007.12

Inclusion of New Heat Generation Term

- Convergence issues with new expression
  - grad(ϕ_n) main issue
    - $\phi_n$and 3/2kT parts work fine
    - E_C and P_nT parts do not
- IV curves using truncated expression (parts that converge) show qualitative improvement
  - Higher I_D at higher V_D
  - But overcompensation
- More investigation needed



Current and Future Work

- Current work
  - Solving convergence challenge for heat generation term
  - Identifying reason for temperature difference between FLOORS and SDevice
- Future work
  - Refining heat generation model
  - Expanding collaborations with materials characterization group